Greenhouse Gas Emission Trends and Projections for Missouri, 1990-2015 Technical Report

Chapter 6

CO_2 Sequestration Due to Forest Growth

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Part 1: Sequestration of CO_2 due to forest growth — trends and projections

Nearly a third of Missouri's total land area is forested. Missouri's 14 million acres of forests are primarily a mixture of various hardwood species, mainly oak and hickory. Over the past several decades, forestry management practices in the state have permitted continued biomass growth in these forested acres.

When forest biomass increases, CO_2 is taken up in woody biomass. Section 1 of this chapter discusses trends and projections in CO_2 uptake by Missouri's forests. The *1990 Inventory* estimates that in the 1990 baseline year biomass growth in Missouri forests took up between 31.4 and 37.9 million tons of CO_2, with a midpoint estimate of 27.1 million tons. A range is estimated due to uncertainty in estimating the uptake that occurs due to the growth of tree roots.

Although the U.S. Forest Service, North Central Forest Experiment Station (NCFES) periodically estimates above-ground biomass in Missouri forests, it does not estimate below-ground biomass. Therefore, estimates of root biomass are based on studies of the ratio of root biomass to above-ground biomass for the species that dominate Missouri forests. These studies have provided a range of results. The low sequestration estimate assumes that biomass in tree roots equals about 18 percent of trees' above-ground biomass; the high estimate assumes that root biomass equals about 43 percent of above-ground biomass.

Uptake must be distinguished from *net sequestration*, which is affected by the impact of forest removals. Forest removals include fire wood, commercial round wood and residue removed from the forest.

Section 2 estimates the impact of forest removals following a simple methodology prescribed in *the State Workbook*.[1] In this simple approach, net sequestration is presumed to equal uptake minus removals. All the estimates of net sequestration in this chapter are based on this methodology. For example, in 1990, the estimated impact of Missouri's forest removals was to offset about 7.5 million tons of forest uptake, resulting in a midpoint net sequestration estimate of about 27 million tons of CO_2.

Section 3 discusses an alternative approach to estimating the impact of forest removals which acknowledges the role of forest products in sequestering carbon. This approach is theoretically more sound but also more complicated. Use of the simpler methodology is a likely source of error in the estimates presented in this chapter, but as Section 3 points out, this source of error must be assessed in the context of other sources of error in the analysis.

Forest biomass growth has been taking place for decades in Missouri's forests and is expected to continue. Table 1 summarizes estimated 1990 through 1996 sequestration trends.

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[1] USEPA, State and Local Climate Change Outreach Program, *State Workbook: Methodologies for Estimating Greenhouse Gas Emissions*, 1995 and 1998 (draft), Washington D.C. Hereafter referred to as the *State Workbook*.

Table 1 - Midpoint estimates of net CO_2 sequestration due to growth of biomass in Missouri forests, 1990-96

Units: 1,000 Short Tons Carbon Dioxide (CO_2)

	1990	1991	1992	1993	1994	1995	1996
Potential sequestration	34,615.00	34,615.00	34,615.00	34,615.00	34,615.00	34,615.00	34,615.00
Removals	7,541.00	7,654.48	7,953.62	8,255.90	8,558.79	8,726.38	8,882.91
Net sequestration	27,074.00	26,960.52	26,661.38	26,359.10	26,056.21	25,888.62	25,732.09

In order to accommodate uncertainty about future forest management in Missouri, the NCFES has developed two scenarios projecting forest removals in Missouri through 2019, a low-removals scenario and a high-removals scenario.[2] These scenarios are integrated into Table 2, which summarizes projections of net sequestration through 2015. The midpoint estimate for removals in Table 2 is based on a numeric average of the NCFES scenarios for the level of forest removals. This study relies on the midpoint estimate for removals when summarizing overall greenhouse gas sinks and sources.[3] Like Table 1, Table 2 uses a midpoint estimate for the ratio of roots to above-ground biomass.

Table 2 - Projected CO_2 sequestration due to growth of biomass in Missouri forests, by level of biomass removals, 1990-96

Units: 1,000 Short Tons Carbon Dioxide (CO_2)

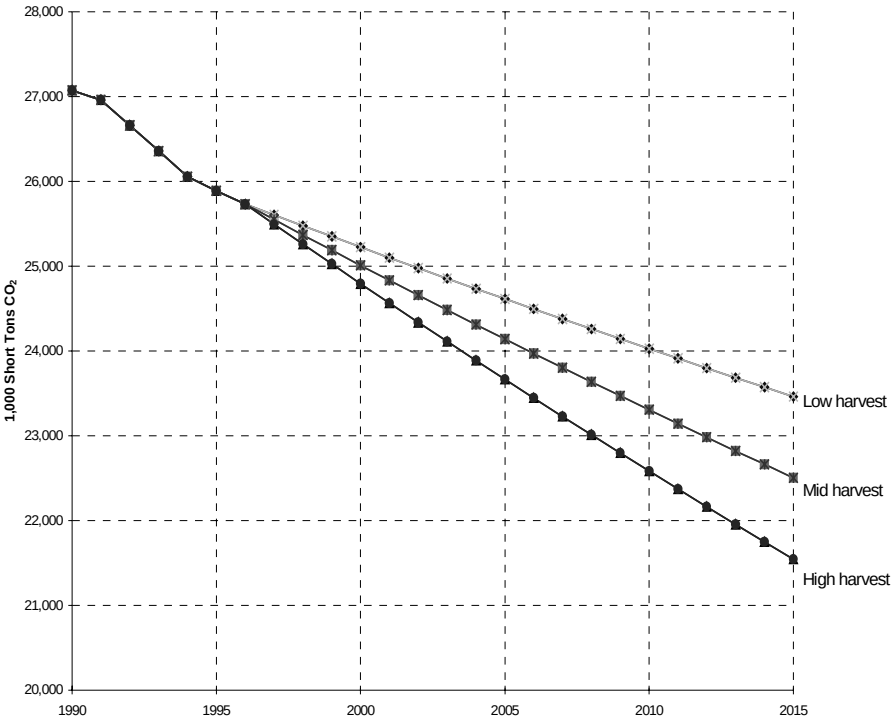
	1990	1995	2000	2005	2010	2015
Potential sequestration	34,615	34,615	34,615	34,615	34,615	34,615
Removals						
Low case	7,541	8,726	9,390	10,001	10,588	11,153
Mid point	7,541	8,726	9,606	10,475	11,310	12,112
High case	7,541	8,726	9,822	10,949	12,032	13,071
Net sequestration						
Low case	27,074	25,889	25,225	24,614	24,027	23,462
Mid point	27,074	25,889	25,009	24,140	23,305	22,503
High case	27,074	25,889	24,793	23,666	22,583	21,544

[2] USDA/NCFES, *Missouri's Forest Resource, 1989: an Analysis*, pp. 21-22.

[3] The rationale for using the midpoint estimate for removals is that it is the single best summary of USFS/NCFES scenarios for low and high growth of removals. However, a case can be made for using the high removals scenario. Dennis May of NCFES has indicated that growth in removals during 1994 through 1996 appears to fit the high growth scenario and that the geographic scope of the market for Missouri pulpwood appears to have grown to include southern Arkansas pulp mills. (Personal communication, 10/15/97). The growth of a "chip mill" industry in Missouri would also put upward pressure on the removal rate.

Chart 1 illustrates the impact of removals, according to the different scenarios, on net sequestration due to forest growth.

Chart 1 - Historic and projected net CO_2 sequestration under the low-, mid- and high-removals scenarios



The following sections discuss the two variables — rate of biomass growth and rate of forest removals — that primarily determine the net sequestration estimate.

Section 1: Forest biomass growth

The trend and projection analyses assume that through 2015, the acreage, species composition and biomass growth rate of Missouri forests will remain constant at 1990 levels.[4] The assumed growth rate for Missouri forest biomass, 3 percent per annum, is taken from a Missouri statewide forest inventory completed in 1989 by the U.S. Forest Service, North Central Forest Experiment Station (NCFES) with assistance from the Missouri Department of Conservation (MDC).

A decrease in biomass growth rate would decrease annual sequestration of CO_2, whereas an increase in the growth rate would increase sequestration. Table 3 summarizes an analysis of the sensitivity of sequestration to the growth rate. A ±1 percent change in the growth rate would change the midpoint estimate for sequestration by about ±33 percent.

Table 3 - Sensitivity of estimates of CO_2 uptake to forest biomass growth rate

Units: 1,000 Short Tons Carbon Dioxide (CO_2)

2.00%	**low**	(20,911)
	high	(25,243)
2.50%	**low**	(26,139)
	high	(31,553)
3.00%	**low**	(31,367)
	high	(37,864)
3.50%	**low**	(36,594)
	high	(44,175)
4.00%	**low**	(41,822)
	high	(50,485)

[4] The *1990 Inventory* found modest increases in total forested acreage. However, some observers of the "chip mill" industry which has recently moved into Missouri have argued that if landowners selling to chip mills fail to follow sustainable harvesting practices, the result could be a reduction in forested acreage. (St. Louis Post Dispatch, "Paper Companies Turn to Missouri," September 21, p. A1.)

In theory, forest maturation could result in a decrease in the biomass growth rate.[5] However, the probability of a shift in growth rate in either direction is not known. Data to assess 1990 to 1996 forest biomass growth trends will not be available until completion of the next statewide inventory, scheduled to be completed in 1999.[6]

[5] Personal communication, Wiley Barbour, USEPA, September 12, 1997.

[6] Personal communication, Mark Hansen, NCFES, April 24, 1997.

Section 2: Forest removals

This section analyzes the impact of forest removals using methodology prescribed in the USEPA's *State Workbook*. This methodology accounts for forest removals by assuming that any increase in forest removals results in a decrease in CO_2 sequestration that would result from forest growth. This methodology, drawn from the *State Workbook*, is acknowledged as valid by the Intergovernmental Panel on Climate Change (IPCC), which serves as the international forum for developing guidelines on methodology for greenhouse gas inventories. However, IPCC also acknowledges an alternative methodology which attempts to account for a variable rate of decay of the carbon in harvested wood depending on its disposition, that is, whether it remains sequestered in a wood product or resides in a landfill where it will be released over time. This alternative methodology, which is discussed in Section 3 of this chapter, is theoretically superior to the methodology prescribed by the *State Workbook* and presented in Section 2. However, as Section 3 explains, use of this more complicated methodology is impractical for this study.

Forest removals include fuelwood, commercial round wood and residue from commercial timber harvests. These quantities are initially estimated in tons of dry matter, which is then multiplied by conversion factors (.498 tons carbon per ton of dry matter, 3.67 tons CO_2 per ton of carbon) to estimate how much CO_2 sequestration is offset by the removals.

Firewood removals are difficult to estimate because more than 99 percent of all firewood is cut by households, and therefore there are no market transactions that can be traced. According to the most recent estimate available, 924,000 cords of fuelwood were removed from Missouri forests in 1987.[7] Assuming 79 cubic feet of dry matter per cord, this was equivalent to about 73 million cubic feet of dry matter. The analysis assumes that fuelwood removals in 1990 were identical to those in 1987 and that fuelwood removals from 1990 to 1996 grew at the same rate as Missouri's population, totaling about 76.3 million cubic feet in 1996.

Commercial roundwood harvest and residue trends for 1991 and 1994 were drawn from Missouri forest inventories completed by NCFES.[8] According to the inventories, 121.4 million cubic feet were harvested in Missouri in 1991, with 67.6 million cubic feet of residue; and 132.6 million cubic feet were harvested in 1994, with 85.6 million cubic feet of residue. Estimates for other years in the period from 1990 to 1996 were extrapolated from this data.

Table 4 summarizes trend estimates for removals in cubic feet, and Table 5 summarizes them in tons of dry matter. In accord with methodology from the *1990 Inventory*, the volume estimates were converted to tons of dry matter using a conversion factor of .016 tons dry matter per cubic foot as follows:

[7] USDA/NCFES, *Residential Fuelwood Production and Sources from Roundwood in Missouri, 1987*, 1991, p. 2.

[8] USDA/NCFES, *Timber Resources of Missouri*, 1994 and 1997 (draft).

Table 4 - Estimated volume of Missouri timber removals (cubic feet) in 1991-96

Units: 1,000 Cubic Feet

	1991	1992	1993	1994	1995	1996
Roundwood	121,400	125,133	128,867	132,600	136,333	140,067
Residue	67,600	73,608	79,615	85,623	86,995	0
Fuelwood	72,996	73,494	74,099	74,726	75,357	75,656
Total	***261,996***	***272,235***	***282,581***	***292,949***	***298,685***	

Table 5 - Estimated Missouri timber removals (tons of dry matter) in 1991-96

Units: 1,000 Tons Dry Matter

	1991	1992	1993	1994	1995	1996
Roundwood	1,942	2,002	2,062	2,122	2,181	2,241
Residue	1,082	1,178	1,274	1,370	1,392	1,413
Fuelwood	1,168	1,176	1,186	1,196	1,206	1,211
Total	***4,192***	***4,356***	***4,521***	***4,687***	***4,779***	***4,865***

Table 6 - Estimated sequestration offset due to Missouri timber removals in 1991-96

Units: 1,000 Short Tons Carbon Dioxide (CO_2)

	1991	1992	1993	1994	1995	1996
Roundwood	3,547	3,656	3,765	3,874	3,983	4,092
Residue	1,975	2,151	2,326	2,502	2,542	2,580
Fuelwood	2,133	2,147	2,165	2,183	2,202	2,210
Total	***7,654***	***7,954***	***8,256***	***8,559***	***8,726***	***8,883***

The commercial roundwood harvest between 1996 and 2015 was projected based on scenarios from the NCFES publication *Missouri's Forest Resources, 1989: An Analysis*. *Forest Resources* presents two scenarios: a low-removals scenario that projects 213 million cubic feet of commercial roundwood removals in 2019 and a high-removals scenario that projects 266 million cubic feet of removals. According to NCFES staff, these projections are reasonable and provide the best available estimate at this time. Values for years between 1996 and 2015 were extrapolated based on average linear growth rate.

Residue between 1996 and 2015 was projected based on the assumption that harvest efficiency — the ratio of commercial roundwood to roundwood plus residue — equaled 61 percent in 1994 and would increase to 67 percent in 2015. The value of residue for intervening years between 1996 and 2015 was extrapolated.

The following tables summarize projection estimates for midpoint estimates of removals in cubic feet and in tons of dry matter, and the resulting estimates of offset CO_2 sequestration. The coefficients and conversion factors are identical with those used to estimate trends, and an identical methodology was used to estimate removals for the low and high harvest scenarios.

Table 7 - Midpoint estimate of volume of Missouri timber removals (cubic feet) in 1991-96

Units: 1,000 Cubic Feet

	1996	2000	2005	2010	2015
Roundwood	140,067	157,359	178,975	200,591	222,207
Residue	88,319	94,578	101,229	106,656	110,937
Fuelwood	75,656	76,855	78,336	79,865	81,434
Total	***304,042***	***328,793***	***358,541***	***387,112***	***414,578***

Table 8 - Midpoint estimate of tonnage of Missouri timber removal in 1991-96

Units: 1,000 Tons Dry Matter

	1996	2000	2005	2010	2015
Roundwood	2,241	2,518	2,864	3,209	3,555
Residue	1,413	1,513	1,620	1,706	1,775
Fuelwood	1,211	1,230	1,253	1,278	1,303
Total	***4,865***	***5,261***	***5,737***	***6,194***	***6,633***

Table 9 - Projected midpoint sequestration offset due to Missouri timber removals, 1996-2015

Units: 1,000 Short Tons Carbon Dioxide (CO_2)

	1996	2000	2005	2010	2015
Roundwood	4,092	4,597	5,229	5,860	6,492
Residue	2,580	2,763	2,958	3,116	3,241
Fuelwood	2,210	2,245	2,289	2,333	2,379
Total	***8,883***	***9,606***	***10,475***	***11,310***	***12,112***

Section 3: Estimates of the impact of biomass removals on carbon sequestration from forest growth in Missouri

As discussed previously, the *State Workbook* endorses a simple method to account for carbon emissions from harvested wood, described here as the "immediate emissions method." This is one of two alternative methodologies recognized by the Intergovernmental Panel on Climate Change (IPCC), which serves as the international forum for developing guidelines on methodology for greenhouse gas inventories. The two alternative methods to account for carbon emissions from harvested wood may be described as follows:[9]

1) the ***carbon pools*** method, which accounts for the variable rate of decay of harvested wood according to its disposition (e.g., product pool, landfill, combustion), or

2) the ***immediate emissions*** method, which assumes that all of the harvested wood replaces wood products that decay in the inventory year so that the amount of carbon in annual harvests equals annual emissions from harvests. The IPCC guidelines refer to this as "the recommended default assumption … for initial calculations."[10]

Previous sections of this chapter make two key assumptions: 1) that biomass in Missouri forests will continue to increase at its historic rate of 3 percent per year; and 2) that the amount of carbon in annual forest harvests equals annual emissions from harvests. These assumptions, combined with a projected increase in forest harvest through 2015, lead to the report's conclusion that net annual sequestration from Missouri forests will decline through that year. In other words, the report projects that total carbon stored in Missouri forests will continue to increase, but the amount of carbon added each year will slowly decline.

The choice of methodology requires discussion because the carbon pools method is theoretically superior to the immediate emissions method. Other things being equal, use of the carbon pools method would probably increase the study's estimate of net CO_2 sequestration from Missouri forests and forest products. However, use of the carbon pools method is impractical for this study.

The following discussion summarizes the use of the carbon pools method in several recent studies, describes the obstacles to its use in this study and discusses how the choice of methodology affects the quality of the estimate.

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[9] IPCC/UNEP/OECD/IEA (1997) *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories,* Paris: Intergovernmental Panel on Climate Change, United Nations Environment Program, Organization for Economic Co-Operation and Development, International Energy Agency. Chapter 5, Box 5, p. 19. The treatment of harvested wood has continued to be a controversial topic among member governments of IPCC; some issues may be resolved by an IPCC Expert Group Meeting scheduled in Dakar, Senegal during 5/4/98-5/9/98. Personal communication, Wiley Barbour, USEPA, 5/7/98.

[10] *ibid.*, p. 19.

Section 4: Use of the "carbon pools" method in current national and global studies

Analyses using the "carbon pools" method treat growing forests as one of several related “carbon pools” that sequester carbon which might otherwise enter the atmosphere as CO_2. From this viewpoint, when biomass is removed from the forest pool, a portion of the carbon continues to be sequestered in these other carbon pools in the form of durable wood products or landfilled product.

This "carbon pools" method has been adopted by several recent studies of the role of forests and wood products in the carbon cycle at a national or global level. For example, a current study by Kenneth Skog concludes that:

> Since 1910, an estimated 2.7 Pg (petagrams; $\times 10^9$ metric tons) of carbon have accumulated and currently reside in wood and paper products in use and in dumps and landfills, including net imports. This is notable compared with the current inventory of carbon in forest trees (13.8 Pg) and forest soils (24.7 Pg). On a yearly basis, net sequestration of carbon in U.S. wood and paper products … is projected to increase … while net additions (sequestration) in forests is projected to decrease … Net sequestration is increasing in products and landfills because of an increase in wood consumption and a decrease in decay in landfills compared with phased-out dumps.[11]

A 1996 study by Heath, Birdsey, Row and Plantinga comes to similar conclusions.[12]

USEPA also adopts this approach in its current (1998) inventory of national greenhouse gas emissions,[13] as follows:

> Timber harvests may not always result in an immediate flux of carbon to the atmosphere. Harvesting, in effect, transfers carbon from one of the "forest pools" to a "product pool." Once in a product pool, the carbon is emitted over time as CO_2 through either combustion or decay of the product. The rate of emission varies considerably among different product pools. For example, if timber is harvested for energy use, combustion results in an immediate release of carbon. Conversely, if timber is harvested and subsequently used as lumber in a house, it may be many decades or even centuries before the lumber is allowed to decay and carbon is released to the atmosphere. Discarded wood and wood products may be stored in landfills for years or decades before they decay.

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[11] Kenneth E. Skog and Geri Nicholson, “Carbon Cycling through Wood Products: The Role of Wood and Paper Products in Carbon Sequestration,” revised April 1998, prepared for publication in *Forest Products Journal*, p. 1.

[12] Heath, L.S., R.A. Birdsey, C. Row, and A.J. Plantinga. 1996. “Carbon pools and fluxes in U.S. forest products.” p. 271–278. In Proceedings of the NATO advanced research workshop. *“The role of global forest ecosystems and forest resource management in the global cycle.”* Banff, Canada. 12–14 Sept. 1994. NATO ASI Series I: Global Environmental Change. Vol. 40. Springer-Verlag, Berlin. Birdsey is the most recognized expert in this field. Skog's paper, *op.cit.*, includes a detailed comparison of the two studies' assumptions, methods and conclusions.

[13] USEPA, Office of Planning, Policy and Evaluation, *Inventory of U.S. Greenhouse Gas Emissions and Sinks*, 3/18/98 draft posted for comment at http://www.epa.gov/globalwarming/inventory/1998-inv.html.

> Because most of the timber that is harvested from U.S. forests is used in wood products and much of the discarded wood products are disposed of by landfilling rather than incineration, significant quantities of harvested carbon are transferred to long-term storage pools rather than being released to the atmosphere. The size of these long-term carbon storage pools has also increased steadily over the last century. [14]

These studies use models that allocate harvested carbon to disposition categories (products, landfills, energy use and emissions) and track the accumulation of carbon in different disposition categories over time. For the studies cited in the this section, Skog used the WOODCARB model. Heath and Birdsey used the HARVCARB model and USEPA is using the HARVCARB model.

The carbon pools methodology is theoretically appealing but demands substantial data and resources. The following section describes the barriers to implementing the approach in state-level studies such as the draft report.

[14] *op. cit.*, pp. 87, 88.

Section 5: Impracticality of the "carbon pools" method at the state level

USEPA's *State Workbook*, the methodological guidebook for state greenhouse gas inventories, instructs states' partners to assume that, when biomass is removed from forests, all carbon contained in the biomass is emitted to the atmosphere at the time of removal. [15] The *State Workbook* states that this is a "legitimate, conservative assumption for initial calculations," citing the following reasons:

1) The measurement process is complicated by the fact that new products from current timber harvests frequently replace existing product stocks[16]; and

2) Although the long-term storage of carbon in wood products and landfilled wood is accounted for in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1996* (USEPA, 1998), this kind of carbon storage cannot be easily estimated on a state-by-state basis because the processes of harvesting wood, manufacturing wood products, and disposing of wood and wood products often cross state lines.

In order to account for replacements, the studies cited in the previous section use models that allocate harvested carbon to disposition categories. However, these models have been created and calibrated only at the global or national level. State-level versions of these models do not exist and are probably impractical. Kenneth Skog, a current authority in the field, has stated that he "can't imagine states doing [the analysis] individually." [17]

A major barrier to building such a state model is that it would require building a series of disposition matrices to account for the disposition of forest harvest and wood products to the various carbon pools at the state level. Data required to build these matrices would include:

a) the disposition of the forest harvest to end uses;

b) the disposition of the end-use products to new stock versus displacement of existing product stock;

c) the disposition of the displaced stock to combustion or other pools such as recycling or landfills; and

d) the disposition over time of end-use products to landfills, combustion or emissions.

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[15] USEPA is considering a revision of the methodology recommended in the *State Workbook* but recognizes the impracticality of requiring each state to do "carbon pools" analysis. A possible solution would be for USEPA to analyze carbon pools at a national level and supply default values to states. However, this solution is not currently funded. Personal communication, Wiley Barbour, USEPA,.4/30/98.

[16] According to IPCC methodological guidelines, in order to include storage of carbon in forest products in its state inventory, Missouri would at minimum need to demonstrate "that existing stocks of long-term forest products are, in fact, increasing." IPCC/UNEP/OECD/IEA, ibid., p. 19.

[17] Personal communication, 4/30/98.

State-level data necessary to build these disposition matrices does not exist. The only available data covers the disposition of forest harvest to primary product categories, such as "saw logs." This data is available from periodic surveys of the disposition of trees and tree material harvested in Missouri by the USDA Forest Service.[18] However, the USDA surveys do not track forest harvest through secondary processing into end uses for the final market, such as pallets or grade lumber.[19]

The second issue cited in the *State Workbook* is that "the processes of harvesting wood, manufacturing wood products, and disposing of wood and wood products often cross state lines." Most of the forest products harvested in Missouri do undergo primary processing in the state.[20] However, much of the product then leaves the state for secondary processing into consumer end products. In addition, many wood-based consumer products manufactured in Missouri leave the state, and many products containing wood are imported into the state. [21]

Missouri is probably a net exporter of saw wood, although construction relies predominantly on imported soft wood products. [22] On the other hand, Missouri is a net importer of pulp, although this could change if so-called pulp mills become widely established in Missouri. Most of the product of pulp mills would be exported for manufacture into paper at plants located outside the state.

Data to track these product movements across state lines is currently unavailable. Furthermore, in the absence of USEPA methodological guidance, a state-level effort to account for product movements across state lines is inadvisable since there is no guarantee that the resulting analysis could be compared to analyses by other states.

There appears to be no practical way to resolve these obstacles to accounting for the disposition of forest harvest into carbon pools. Therefore, this study follows the guidance of the USEPA *State Workbook* and adopts the "immediate emissions" method of accounting for carbon emissions from harvested wood.

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[18] USDA Forest Service, North Central Forest Experiment Station, *Missouri Timber Industry —An Assessment of Timber Product and Use*, various years.

[19] Personal communication, Shelby Jones, Mo. Dept. of Conservation, 4/30/98.

[20] Personal communication, Ron Hackett, USDA Forest Service, North Central Forest Experiment Station, 4/30/98.

[21] Shelby Jones, *op.cit*.

[22] Shelby Jones, *op.cit*.

Section 6: The effect of methodology choice on estimates in the draft report

Other things being equal, use of the immediate emissions method leads to a lower estimate of net sequestration from Missouri forests and forest products than would an estimate generated by the carbon pools method.

Most of Missouri's roundwood harvest goes into primary product categories such as saw logs, cooperage logs, veneer logs and miscellaneous categories. Much of the wood from this primary processing probably goes into secondary manufactured products, which last for a number of years, and then into landfills, where it may be sequestered for many more years.

The carbon contained in harvest residues appears less likely to be sequestered in product and landfill pools for long periods of time. About 85 percent of Missouri's charcoal and most of its pulp derive from mill residue rather than roundwood. Most charcoal is manufactured into briquettes for combustion, although some is manufactured into specialty products for the chemical industry. Pulp from harvest residues as well as the limited amount of pulp currently derived from Missouri's roundwood harvest goes into paper products. In general, paper products are subject to more rapid decay than solid wood. Section 4 discusses factors that can affect the rate of decay of paper products.

In order to quantify the difference in estimates produced using the two methodologies, it would be necessary to estimate product disposition matrices such as those described in Section 2. Given the nature of Missouri's saw wood-based timber economy, the difference could be significant. It seems likely that a substantial percentage of the carbon from harvest remains sequestered for long periods in the wood-product carbon pool.

In evaluating the draft report's estimate of net sequestration from forest growth and forest products, one should take into account that methodology in this area is unsettled[23] and that some necessary data sources are underdeveloped. Consequently, the estimate offered in this report is subject to several sources of error that might lead to an underestimate or overestimate of net sequestration. Moreover, these different sources of error may offset each other.

Possible sources of an underestimate of net sequestration include:

1) The use of the immediate emissions method for estimating the impact of removals.

2) The assumption that the growth rate of forest biomass will remain constant at 3 percent. This growth rate reflects past management practices. Management practices could change in ways that would increase the growth rate. As sensitivity analysis in the report indicates, a 1 percent increase in forest growth rate would lead to a 33 percent increase in sequestration, other things being equal.[24]

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[23] USEPA State and Local Climate Change Outreach Program staff have that methodology for estimates of emissions from forest and land use changes is problematic and under revision.

[24] Chapter 5, Table 46, p. 53.

a) Findings from forest inventories indicate the quality of the current forest sites will support growth rates greater than the historic 3 percent rate.[25]

b) Forest management practices could change in response to an increase in Missouri's pulpwood harvest, for example through the widespread introduction of "chip mills." A preliminary analysis provided by the Missouri Department of Conservation[26] suggests that an increase in pulpwood harvest would favor management practices that tend to increase forest growth rate. According to this analysis, increased pulpwood harvest leads to removal of materials that impede growth rate (small diameter and small stem trees, understory species). When these materials are removed, the remaining timber grows faster. In addition, pulpwood harvesting tends to result in even-age management systems that result in more wood fiber production than uneven age systems associated with sawlog production. The analysis is based in part on observation of the impact of increased pulpwood harvest on timber growth rates in the Southeastern states.[27]

Possible sources of an overestimate of net sequestration include:

1) Forest growth rate could decrease as well as increase. As the draft report notes, forest growth rate could decrease due to maturation, such as has occurred in a number of Northeastern states. Forest growth rate could also decrease if landowners were to move away from sustainable forest management practices. A 1 percent decrease in forest growth rate would decrease sequestration by about 33 percent.

2) Although an increase in pulpwood harvest could increase biomass growth rate, it could decrease the average storage duration of carbon derived from Missouri forest harvest. In general, the paper products manufactured from pulpwood harvest are subject to more rapid decay than the solid wood products produced from Missouri's traditional saw wood timber economy. However, the length of time that the carbon in paper is sequestered in product and landfill pools can vary depending on several factors:

   a) Recycling can extend the period during which the carbon is stored in a product pool.

   b) Paper with high lignin content decays slowly in landfills.

   c) Some studies indicate that paper in modern landfills may escape decay for very long periods of time.[28]

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[25] Shelby Jones, personal communication, 4/30/98.

[26] Shelby Jones, ibid.

[27] A premise of this analysis is that landowners and loggers would make a long-term commitment to managing forested acres in a sustainable manner. A St. Louis Post Dispatch article, "Paper Companies Turn to Missouri - And Its Trees," discusses Department of Conservation goals of assisting landowners in practices such as stand thinning and selective harvesting. (Sunday, Sept. 21, 1997, p. 8.)

[28] J. A. Micales & K. E. Skog, See *The Decomposition of Forest Products in Landfills*, International Biodeterioration & Biodegradation Vol. 39, No. 2–3 (1997), 145–158.

3) Finally, the harvest growth rate projected by the study may be low. The only available projection of forest harvest appears in a *Forest Resource* study completed in 1989.[29] This source projects a linear growth curve for forest removals. Since 1989, the growth curve for forest removals has grown steeper, following a curvilinear growth pattern. Preliminary returns from a 1997 *Forest Resource* study indicate the faster growth rate established in the first half of the decade will probably continue. After completion of the 1997 *Forest Resource* study, four data points will be available, providing the basis for more reliable projections.[30]

[29] USDA Forest Service, North Central Forest Experiment Station, *Missouri's Forest Resource, 1989: An Analysis*, 1989. This projection is discussed in Chapter 5, Part 5, Section 2 of this study.

[30] Shelby Jones, Personal communication, Missouri Dept. of Conservation, 4/30/98. The four data points are *Forest Resource* studies for 1989, 1991, 1994 and 1997.